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RICE BRAN OIL: ITS THERAPEUTIC POTENTIAL

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ABSTRACT

Rice bran oil (RBO), a unique cooking oil is produced from the pericarp and germ of *Oryza sativa* seeds. The chemical composition of RBO is similar to groundnut oil (GNO), however, high content of unsaponifiables, contrast to other refined vegetable oils makes the oil worth exploiting its therapeutic potential. With the advent of "Nutrition Transition", in industrialized world, there has been explosion of consumer interest in the active role of underutilized natural foods in the well being and longevity as well as prevention of degenerative diseases. The review gives a brief account of the composition, bioactive components, their biochemical roles and therapeutic characteristics. An attempt has been made to include the available literature on the effectiveness of RBO and its phytochemicals in the management of chronic diseases.

KEYWORDS: Rice Bran Oil, Hypolipidemic, Hypocholesterolemic; oxidative stress, Oryzanol, Tocotrienols

INTRODUCTION

Rice bran oil (RBO), a unique cooking oil iss produced from the pericarp and germ of *Oryza sativa* seeds. It constitutes about 10% of rough rice grain and contains 18-22% oil. It is the only oil which, besides having balanced fatty acid composition and ideal PUFA/SFA and fair linoleic acid (LA)/ α-linoleic acid (ALNA) ratio (Ghafoorunissa, 1994), contains three categories of natural antioxidants i.e. tocopherols, tocotrienols and oryzanol. High content of these antioxidants impart higher oxidative stability and longer shelf life as compared to other edible oils (Raghuram and Rukmini, 1995).

RBO has been used as edible oil in Japan for over two decades and is popularly known as *"Heart Oil"* in Japan. In recent years, U.S. scientists have also shown a tremendous interest in cholesterol lowering properties of RBO and this oil has acquired the status of *'Health food'* there as well. Since India ranks first in the annual production of crude RBO (500,000 tonnes) and refined RBO (>400,000 tonnes) (Gopalkrishna et al., 2006), the possibility of exploiting rice bran as a source of edible oil has come into greater focus in our country in recent years and the nutritional composition, toxicological safety and hypolipidemic action of RBO have been studied with interest.

The oil is pale yellow, limpid (at 20^0C) and odourless with an acid index of <0.50, density at 20^0C between 0.92 and 0.93, refractive index at 20^0C between 1.47 and 1.47 and smoke point >200^0C and has a pleasant lightly sweet flavour (Cicero and Gaddi, 2001).

COMPOSITION

The chemical composition of RBO is very close to that of groundnut oil (GNO). It has high unsaponifiable

fraction (1.5-2.6%) in contrast to other refined vegetable oils that contains only 0.3-0.9% (Rong et al., 1997). It contains oleic acid (38.4%) as 2-oleate, linoleic acid (34.4%) and α-linolenic acid (2.2%) as unsaturated fatty acid and palmitic (21.5%) and stearic acid (2.9%) as saturated fatty acid (Edwards and Radcliffe, 1994; Radcliffe et al., 1997).

In contrast to other common refined vegetable oils; crude RBO contains an unusually high content of unsaponifiables (up to 5%) mainly composed of sterols (43%), 4- methyl sterols (10%), triterpene alcohols (28%) and less polar components (19%) (Sayre and Saunders, 1990). Phytosterols include β- sitosterol (900mg %), campesterols (500mg %), stigmasterol (250mg %), squalene (320mg %) and γ- oryzanol (1.6%). γ- oryzanol is a mixture of ferulic acid esters of triterpene alcohols such as cycloartanol (106 mg/dl), cycloartenol (482 mg/dl) and 24-methylene cycloartanol (494 mg/dl) (Metwally et al., 1974; Norton, 1995). It also contains small variable quantity of tocotrienols (72-612 ppm especially β and γ tocotrienols) (Rukmani and Raghuram, 1991). Moreover, it is naturally rich in α-tocopherol (100mg %). However, the levels of neutraceutical lipid components tocols (tocopherols and tocotrienols), phytosterol, γ- oryzanol, octasonal and squalene, as well as total lipids in rice decreased markedly with milling (Ha et al., 2006).

Crude RBO is not suitable for human consumption due to non edible colour and flavour components and must be refined. A great deal of technological advancement has been achieved in the processing of RBO, yet, the most useful method to minimize the formation of free fatty acids in RBO and reduce refining losses are still a major constraint in the industry.

Long back, Rao et al., (1978) conducted a study on refining and storage of rice bran oil and concluded that incorporation of molasses prior to alkali refining result into 30% reduction of losses. Furthermore, storage of raw, refined and bleached RBOs for 370 days at ambient temperature resulted in gradual rise in FFA, peroxide value in neutralized and bleached oils and slight decrease in the colour of crude and bleached oils. Conventional refining, however, leads to considerable loss of minor components (Kochhar, 1983). RBO is produced by either chemical or physical refining. In chemical refining, sodium hydroxide is used to remove FFA and in physical refining dry steam stripping under vacuum is used to remove FFA. During chemical refining the alkali added reacts with FFA and forms soap. The oryzanol present in the crude oil is carried along with soap stock to an extent of 80-90%. However, it does not distill along with free fatty acid (FFA) during physical refining (steam stripping distillation) and almost 90% is retained in refined oil (Gopalkrishna et al., 2001). A study demonstrated that physically refined RBO contains up to 3.5% non saponifiable components and 10 times more oryzanol content than alkali refined RBO (Rong et al., 1994). Likewise, Gopalkrishna et al., (2006) showed that physically refined RBO has medium to high oryzanol levels (0.56- 1.39%) and the chemically refined oil has low to very low levels of oryzanol (0.14-0.18%). Similarly, Hoed et al., (2006) studied the influence of chemical refining on the major and minor components of RBO and concluded that alkali treatment results in significant loss of oryzanol and change in the phytosterol composition. Phytosterols and tocotrienols are stripped during deodorization. However, it does effect oryzanol concentration. Furthermore, complete refining removed 99.5% FFA content. Deodorization can form trans fatty acid but the content generally remains below 1%.

NUTRITIONAL EVALUATION

Organoleptic studies of various food products prepared in RBO revealed good acceptability. A study showed that soft served ice-cream prepared by replacing milk fat with RBO (5%-35%) was well accepted at all the levels of incorporation except for the flavour at 35% (Sharma et al., 2006). Another study demonstrated that by increasing the

percentage of RBO in baked products like cookies, the TBA number decreases and the onset of rancidity is delayed, thus extending the shelf life of the product **(**Sharif et al., 2003**).** Valsalan et al., (2004) assessed RBO as a cooking medium and concluded that food fried in RBO has less oil uptake and obtained high mean score on organoleptic evaluation as compared to ground nut oil. Similarly, Gopala Krishna et al., (2005) studied the frying performance of processed rice bran oil and concluded that both physically and chemically refined RBO had higher thermal and oxidative stability than sunflower oil and may be used for deep fat frying. However, frying was accompanied by foaming which was due to the presence of partial acylglycerols and not due to any fat deterioration or prolonged frying.

BIOACTIVE COMPONENTS

Tocotrienols

Tocotrienols are analogous to tocopherols (Vitamin E) and are mainly concentrated in unsaponifiable matter of RBO. They are also found in aleurone and subcutaneous layers of cereal seeds and in palm oil. RBO is rich in total tocols (500mg/dl); of which one third is tocopherols and two thirds tocotrienols and these may also contribute to reduction in blood cholesterol.

Tocotrienols consist of a chroman ring similar to tocopherols but has a long unsaturated phytyl tail with three isolated double bonds at 3`, 7`and 11` position. Four different isomers of tocotrienols designated as alpha, beta, gamma and delta- tocotrienols exist which differ only in the number and position of methyl groups on the chroman ring. This chroman system forms the basis for the antioxidant potential and the unsaturation in the side chain is essential for inhibition of HMG Co A reductase activity (Quereshi and Quereshi, 1993; Pearce et al., 1994 Quereshi et al., 2000). α-Tocotrienol exerts 45% of vitamin E activity. γ-Tocotrienol is the main and the most potent cholesterol lowering tocotrienol. Commercially available RBO may contain 98mg of γ-tocotrienol per 100g of oil (De Deckere and Korver, 1996).

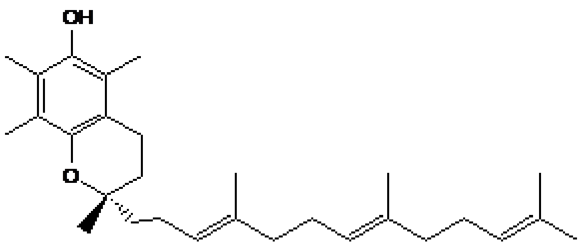


Figure 1: Structure of Tocotrienol

Table 1: Position of Methyl Groups on Aromatic Ring of Tocotrienol

Position of Methyl Groups on Aromatic Ring	Tocotrienol Structure
5,7,8	alpha-Tocotrienol
5,8	beta-Tocotrienol
7,8	beta-Tocotrienol
8	delta-Tocotrienol

Absorption and Transport

The fate of supplemental tocotrienols and the relationship between intestinal absorption, blood vessels and tissue distribution is still not fully understood. However, it seems that their absorption is similar to the absorption of tocopherols

and other non polar lipids like triglycerides and cholesterol. They are emulsified by the bile and are incorporated into micelles along with other fat soluble compounds. However, their transport and tissue uptake differs from that of α-tocopherols. They disappear from plasma along with chylomicron clearance and are deposited in conjunction with triglycerides in adipose tissue (Hayes et al., 1993). Studies have shown that when tocotrienols were administered in high doses to animals and humans; sustained plasma levels were not maintained. In addition, a significant difference in serum tocotrienols level was not observed in control and treated groups when fed atherogenic diets along with high dose of tocotrienols to rats (Watkins et al., 1999). Long back, a study reported that when rats were fed large doses of tocols by gavage, equal or greater amounts of tocotrienols were found in heart, muscle and kidneys as compared with the respective tocopherols. Furthermore, the distribution in tissues depends upon the tissue need. In a study using hairless mice; it was found that tocotrienols levels were highest in skin, accounting for 15% of total body tocols and 1% in kidney, liver and heart (Pearson and Barnes, 1970).

Biochemical Role of Tocotrienols

Extensive research *in vitro* and *in vivo* has shown that tocotrienols can suppress HMG CoA reductase activity, the rate limiting enzyme of cholesterol biosynthesis and subsequently to decrease serum cholesterol levels (Qureshi et al., 1991; 1995; Khor et al., 1995; Parker et al., 1993). Watkins et al., (1993) stated that supplementation with γ- tocotrienol alone or in combination with α-tocopherol resulted in decreased concentration of plasma, total cholesterol, LDL-C, VLDL-C and triglycerides. In addition, there was significant decrease in thiobarbituric acid reactive substances and fatty acid hydroperoxides. However, the effect was more pronounced in the group supplemented with the combination of two.

It has been seen that even though tocotrienols are less biologically active they have higher free radical scavenging properties as cell membrane constituents (Yamaoka et al., 1990) and protect unsaturated lipids against peroxidation (Tappel, 1972) by a mechanism to donate phenolic hydrogens to lipid free radicals (Burton and Ingold, 1989; Goh et al., 1990; Serbinova et al., 1991). Antioxidant actions of tocotrienols have been shown in several *in vitro* systems. Depending upon the test system used, α- tocotrienols showed higher, equal or lower potency than did α- tocopherol and the regeneration of α- tocotrienols from the α- tocotrienols radical was more effective than for α- tocopherol (Serbinova et al., 1993).

Some studies have suggested that tocotrienols may possess anticancer properties (Gould et al., 1991).It has been reported that in addition to other isoprenoids, tocotrienols might suppress tumor cell growth by inhibiting HMG CoA reductase (Elson and Quereshi, 1995). Nesaretnam et al., (1995; 1998) demonstrated that tocotrienols have inhibitory effect on the growth of breast cancer cells.

Tocotrienols protect the blood vessels by preventing the oxidation of LDL-C. They have been shown to strengthen arterial walls, reduce build up of atherosclerotic plaque in blood vessels and support blood flow through arteries. Quereshi et al., (2001a) found that novel tocotrienols [desmethyl (d-P_{21}-T3) and didesmethyl (d-P_{25}-T3) tocotrienols] resulted in significant reduction in the size of atherosclerotic lesions. Furthermore, it may prevent or reverse the blood clots and lesions that may lead to diseases like myocardial infarction, stroke and other blood system thromboses. Moreover, these novel tocotrienols have superior efficacy in hypercholesterolemic, antioxidant, anti-inflamatory, antithrombotic and anticancer activities compared with the known tocotrienols and vitamin E (Qureshi et al., 2000; 2001b)

Thus, besides being a cholesterol reducing agent and a powerful antioxidant they are also known to have anti-

thrombotic, anticancer (especially against skin and breast); antitumor activity ; antiatherogenic effects and anti ageing properties (Ha et al., 2006).

Oryzanol

Oryzanol is a mixture of sterol esters of ferulic acid and was first isolated in 1954 (Kaneko andTsuchiya, 1955). The main sterols esterified are cycloartenol and 24-methylene cycloartanol (4,4`-dimethylsterols) and β- sitisterol and campesterol (4-desmethylsterols). The composition of oryzanol varies with the rice variety (DeDeckere and Korver, 1996).

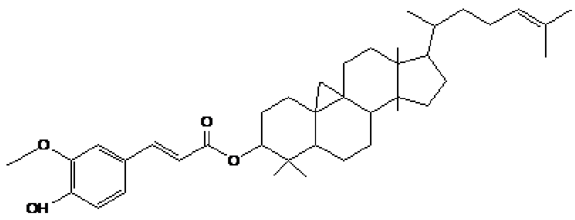


Figure 2: Structure of Cycloarteryl Ferulate

Biochemical Role of Oryzanol

There has been considerable interest in oryzanol due to its many pharmacological uses like growth accelerating action in animals, regulation of oesterous cycle in rats and ability to promote skin capillary circulation. It is also reported to have anti-itching, anti-dandruff action and has been used in cosmetics and dentifrice preparations and is a good antioxidant for oils and fats (Seetharamaiah and Prabhakar, 1986).

It has been shown that oryzanol inhibit linoleic acid oxidation and cholesterol oxidation to a greater extent than vitamin E components. Furthermore, oyzanol components namely cycloartenyl ferulate and 24- methylene cycloartenyl were shown to act as antioxidants in methyl linoleate bulk and multiphase lipid systems and as radical scavengers. (Wilson et al., 2007).

Long back, Sakomato et al., (1987) noted that γ-oryzanol and cycloartenol ferulate have antihyperlipidemic action and this is more pronounced when administered intravenously rather than, through oral route. Seetharamaiah and Chandrasekhara, (1988) concluded that 0.5% oryzanol in diet significantly reduced hypertriglyceridemia induced by fructose in rats. Epidemiological evidences have attributed the cholesterol lowering property of RBO to the presence of this unique component in the oil which is not found in any other edible oil and also to some other components present in unsaponifiable matter (Seetharamaiah and Chandrasekhara, 1989; Rong et al., 1997). It is possible that γ-oryzanol, antihypercholesterolemic effect is partially due to its sterol moiety which splits off from ferulic acid part in small intestines by cholesterol esterase (Fujiwara et al., 1983; Swell et al., 1954). Ferulic acid alone when adsorbed and metabolized has shown an intrinsic hypolipidemic effect in some studies (Srinivasan and Satyanarayana, 1989; Sharma, 1980). However, a comparative study conducted to evaluate hypocholesterolemic activities of oryzanol, curcumin and ferulic acid revealed that oryzanol is more potent than the other two Seetharamaiah and Chandrasekhara, 1993). Likewise, Wilson et al., (2007) suggested that at equal dietary levels, oryzanol has a greater effect on lowering plasma non HDL-C levels and raising plasma HDL-C as compared to ferulic acid possibly by increasing fecal excretion of cholesterol and its metabolites. A study demonstrated that oryzanol exerts hypocholesterolemic effect in experimental animals by suppressing the HMG Co.A reductase activity inhibiting adsorption of dietary cholesterol and increased fecal excretion of bile acids (Seetharamaiah and Chandrasekhara, 1990a). Rong et al., (1997) suggested that oryzanol interferes with cholesterol

absorption by the mode of luminal action or intercellular events but does not affect *de novo* cholesterol synthesis in the intestinal mucosa. Furthermore, the study concluded that the cholesterol lowering action of oryzanol was associated with significant reductions in aortic fatty streak formation. Ausman et al., (2005) studied the mechanism of hypocholesterolemic effect of physically refined RBO (PRBO) and examined its effect on aortic fatty streak formation. The authors suggested that lipid lowering of PRBO was associated with decreased cholesterol absorption but not hepatic cholesterol synthesis. Moreover, the decrease in fatty streak formation was due to its nontriglyceride components. Yoshino et al., (1989) concluded that gamma- oryzanol has the strong potential to be a useful agent for the safe and effective long term control of plasma cholesterol levels in patients with mild hypercholesterolemia.

Oryzanol is also known to have several other benefits like effective in treatment of a broad range of gastro intestinal disorders including stress induced gastric and duodenal ulcers, neuroendocrinological, anabolic and dermatological disorders (Cicero and Gaddi, 2001). γ- oryzanol has also been used to treat nerve imbalance and disorders of menopause (Ha et al.,2006). Another study reported that oryzanol fed along with high cholesterol diet significantly inhibits platelet aggregation induced by ADP and totally inhibited aggregation induced by collagen (Seetharamaiah et al., 1990b).

Studies have shown that ferulic acid may have anticarcinogenic properties through the inhibition of the formation of N-nitroso compounds and has been found to suppress benzo (a) pyrene- induced neoplasia in the fore stomach of mice. Oryzanol did not appear to be carcinogenic. This was supported by the study which showed that feeding 2g oryzanol/kg body weight/day for up to 2 years to the experimental animals did not lead to significant increase in the incidence of tumors.

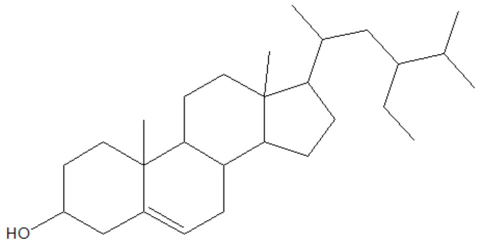
Studies have shown that gamma oryzanol increases muscle growth and sports performance (Fry et al., 1997). It might enhance endurance and muscle building capacity by hindering the production of free radicals in muscle tissue, which theoretically could lessen muscle exhausting and fatigue in reaction to anaerobic exercise. Gamma oryzanol also increases the levels of growth hormone, testosterone, and other anabolic or muscle building hormones. There is limited evidence available to support gamma oryzanol effects on muscular strength and anthropometric measurements during resistance training (Deuster et al., 2004). Bucci et al., 1990, found that the intake of 30 mg ferulic acid per day (extracted from gamma oryzanol) for eight weeks resulted in increasing body weight and muscular strength in weight lifters. In another study conducted by Fry et al (1997) muscular strength was changed after 500 mg/day gamma oryzanol supplementation in adults with age ≥40 yr. 600 mg/day gamma oryzanol supplementation during the 9-week resistance training did not change anthropometric and body measurements, but it increased muscular strength in young healthy males (Eslami et al., 2014).

Jung et al., (2015) reported in the study that oryzanol induces adipocyte differentiation through the induction of PPAR-γ and C/EBPα expression, which may be mediated via the activity of mTORC1 probably oryzanol may stimulate glucose uptake via regulation of mTORC1 signaling. Thus oryzanol may contribute for the health benefits obesity-associated metabolic disorders.

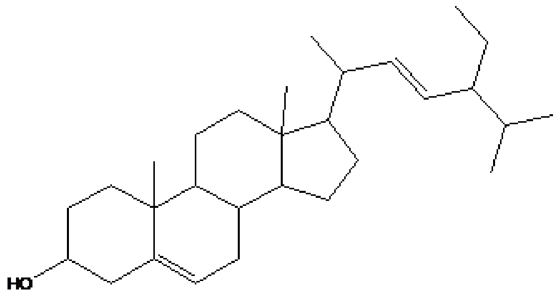
Phytosterols

Phytosterols are minor constituents in the unsaponifiable fraction and constitutes an average 0.3 to 2% of oil. They are non nutritive components and have been shown to inhibit cholesterol absorption in the small intestine. Therefore, they can be used to decrease the plasma cholesterol concentration in hypercholesterolemic subjects.

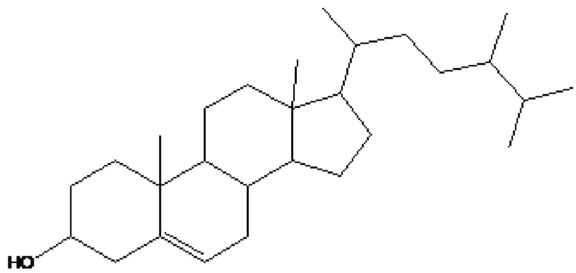
Three groups of phytosterols are present in crude RBO: 4, 4` - dimethyl sterols, 4- monomethylsterols and 4-desmethylsterols. In addition, it contains 4- monomethylsterols with an ethylidiene side chain (e.g., citrostadienol) which may contribute to the oxidative stability of RBO during heating at frying temperatures. Furthermore, a few studies have shown a lower risk for colon cancer with the increased intake of phytosterols (DeDecker and Korver, 1996).



(A) β-Sitosterol



(B) Stigmasterol



(C) Campesterol

Figure 3: (A, B, C) Structures of Phytosterols

Vissers et al., (2000) concluded that 2.1g plant sterols/day from RBO lowered serum total cholesterol by 5%and LDL-C by 9% in normolipidemic humans. Moreover, the hypocholesterolemic effect is probably due to β- sitosterol and other 4-desmethyl sterols and not 4, 4`dimethylsterols. Yoshida and Niki, (2003) stated that phytosterols acts as an antioxidant, a modest radical scavenger in solution and physically by packing and stabilizing the membrane.

Squalene

Squalene, a C_{30} triterpenoid hydrocarbon, is made up of six (*trans*-1, 4)-isoprene units linked as two farnesyl (head-to-tail) groups that are joined tail to tail in the center. It is a biosynthetic precursor to all steroids and has many applications in pharmaceutical and cosmetic industries.

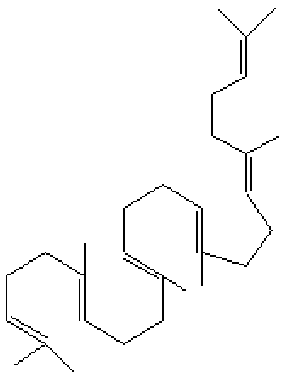


Figure 4: Structure of Squalene

In humans about 60% of dietary squalene is absorbed. It is transported in serum generally in association with very low density lipoproteins (VLDL) and is distributed with greatest concentration in the skin. Stuchik and Zak, (2002) reported that supplementing diet with squalene can reduce cholesterol and triglyceride levels in experimental animals. However, two human reports indicated no change in cholesterol absorption (Standberg et al., 1990; Miettinen and Vanhenen, 1994). As compared to other edible oils, RBO has higher content of squalene (320 mg/dl) which is reported to be a quencher of singlet oxygen and other free radicals. It protects skin from lipid peroxidation due to exposure to UV radiation and is beneficial in maintaining the tone of skin. Studies suggest that squalene possesses chemopreventive activity against some type of cancers (Newmark, 1997; Rao et al., 1998).

HYPOCHOLESTEROLEMIC EFFECTS

As the fatty acid profile and glyceride composition of RBO and ground nut oil (GNO) are similar, the minor constituents in unsaponifiable fraction may be responsible for the hypocholesterolemic action of RBO. This was confirmed by adding unsaponifiable matter of RBO [phytosterols (1.8%) and triterpene alcohol (1.7%) fractionated individually] to atherogenic diet at quantities present in RBO. Results revealed significant reduction in plasma cholesterol and triglycerides (Rukmini and Raghuram, 1991). Experimental evidence suggests that cycloartenol and triterpene alcohol present in high amounts in RBO is absorbed and accumulated in liver (Kiribuchi et al., 1988). Since its chemical structure is similar to cholesterol, it competes for the cholesterol binding sites causing greater metabolism and excretion of cholesterol as bile salts and pigments. Further, triterpene alcohols inhibit cholesterol esterase activity non competitively and as a result, cholesterol esters are slowly hydrolysed leading to delay in cholesterol absorption (Raghuram and Rukmini, 1995).

Studies have reported that the unsaponifiables of RBO not only lowered serum total cholesterol and LDL-C but also raised HDL-C in rats and these alterations in lipoprotein cholesterol were associated with increased faecal excretion of neutral sterols and total bile acid (Sharma and Rukmini, 1986; Seetharamaiah and Chandrasekhara, 1989). Sharma and Rukmini, (1986; 1987) demonstrated that rats fed with RBO at a 10% level in the diet for a period of 8 weeks significantly decreased plasma TC, LDL-C, VLDL-C levels and increased HDL-C levels. Furthermore, liver cholesterol and triglycerides were also reduced while fecal excretion of neutral sterols and bile acids were increased. Likewise, Purushothama et al., (1995) studied the effect of feeding two levels of RBO (5% and 20% of the diet) on growth, plasma and liver lipid parameters of wistar rats and compared with those produced in animals fed by the same quantity of peanut oil. The authors reported that 20% of RBO in diet of experimental animals increased HDL-C and decreased LDL-C and VLDL-C. However, no significant difference was observed in plasma cholesterol/phospholipids ratio, in

polyunsaturated/saturated fatty acid ratio, in oleic/linoleic, oleic/stearic, palmitoleic/palmitic, oleic/palmitic and oleic/palmitoleic ratios between the two groups. Moreover, they suggested that feeding high level of RBO has no deleterious effect on growth and blood lipid profile of rats. Another study reported that RBO fed singly and in blends with other neutraceuticals resulted in marked improvement in serum and hepatic lipid- lipoprotein profile, and strengthening antioxidant defense system by decreasing oxidative stress build up in high fat high cholesterol fed rats (Chauhan et al., 2010). Another study conducted by Ha et al., (2005) examined the effects of bioactive substances in RBO on lipid parameters and lipid peroxidation in serum and liver. The study concluded that the bioactive substances can alleviate the liver damage by suppressing lipid peroxidation and may have a protective role against alterations caused by hypercholesterolemic diet. Having assessed the anti hyperlipidemic property, the following studies examined the effect of blending RBO with other less expensive vegetable oils to improve the oxidative stability, cost and efficacy and plasma lipid profile. The first study conducted by Suzuki and Oshima, (1970) showed that RBO had greater serum cholesterol lowering effect than corn, safflower or sunflower oil. In addition, daily consumption of RBO (60g) in combination with safflower oil (70:30 ratios) has been shown to substantially lower high plasma total cholesterol to normal levels within 7 days. It is suggested that high linolenic acid content of safflower oil in combination with micronutrients of RBO unsaponifiable fraction acts synergistically to lower cholesterol levels (Raghuram and Rukmini, 1995). A similar study conducted by Sunitha et al., (1997) showed significant reduction in non HDL-C levels and increase in HDL-C levels in animals fed on either high cholesterol or cholesterol free diet. Furthermore, fecal excretion of neutral sterols and bile acids were increased with the use of RBO blends. In addition, the high content of tocols in RBO improved the oxidative stability and resulted in economic advantage. In the same vein, Koba et al., (2000) have shown that feeding rats with a diet containing 10% fat with and without cholesterol. The fat was either RBO or safflower oil (SFO) alone or the blend of these two oils in the ratio of 7:3, 5:5, or 3:7. Without cholesterol supplementation, there was no significant difference in serum and liver total cholesterol (TC). However, the HDL-C levels and HDL/TC ratio increased in RBO containing diets. On the contrary, it was observed that supplementing diets with 0.5% cholesterol significantly increased total cholesterol in both serum and liver. Increasing RBO in the diet further raised TC in serum and reduced in liver. It is suggested that probably smaller percentages of PUFA (18:2n-6) in RBO containing diets than in SFO might have reduced their ability to dispose the circulating serum cholesterol in to liver. Chauhan et al., 2015a demonstrated that rice bran oil and oryzanol effectively regulates lipid lipoprotein metabolism and its antioxygenic potential protects against oxidative stress thus can be used as therapeutic weapon in the management of dyslipidemia and associated cardiovascular diseases.

The hypolipidemic effect of RBO was investigated in non human primates fed semi purified diets containing blend of oils which included RBO at 20-25%Kcal as dietary fat. The study demonstrated that the degree of serum TC and LDL-C reduction was highly correlated with initial serum cholesterol levels in monkeys fed a standard diet. Further, RBO supplementation in the diet significantly influenced serum TC, LDL-C and apolipoprotein B causing up to 40% reduction in LDL-C without significantly affecting apolipoprotein A-I and HDL-C plasma level when RBO was the sole dietary oil (Nicolosi et al., 1991). Another study conducted by Lichenstein et al., (1994) concluded that RBO is comparable to corn, canola and olive oil in terms of lowering plasma lipid levels and improving the cardiovascular risk profile. The authors further suggested that hypocholesterolemic effect of the former may be due to some component in unsaponifiable fraction of the oil which may have exerted a greater effect on plasma cholesterol relative to other vegetable oils that can be ascribed to the fatty acid composition of oil itself. Reena and Lokesh, (2007) suggested that feeding fats containing blended oils (RBO, coconut oil and sesame oil) with balanced fatty acids (1:1:1) lowers serum and liver lipids. Moreover, interesterified

oils prepared using lipase have a further lowering effect thus indicating that atherogenic potentials of a saturated fatty acid containing coconut oil can be significantly decreased by blending with an oil rich in unsaturated lipids in appropriate amounts and interesterification of blended oil.

ANTIDIABETIC EFFECTS

RBO owing to its high content of unsaponifiable matter and radical scavenging properties have antidiabetic potential, though the studies are comparatively less. Chen et al., 2006, showed that in streptozotocin-induced diabetic rat model, plasma and liver triglyceride (TG) concentrations and insulin resistance decreased significantly and fecal neutral sterol concentrations and bile acid excretion increased after 4 wk of feeding with 15% RBO. Another study pointed out that consumption of 18 g rice bran oil modified milk daily for 5 weeks significantly decreased total serum cholesterol concentrations and tended to decrease low density lipoprotein cholesterol concentrations in patients with type 2 diabetes. However, no significant influence on insulin resistance was observed (Lai et al., 2012). Kozuka et al., 2012 demonstrated that brown rice and Oryzanol improves glucose metabolism, reduce hypothalamic ER stress, and, consequently, attenuate the preference for dietary fat in mice fed on HFD. Chou et al., (2008) reported that RBO reduces lipid abnormalities; atherogenic index with simultaneous increase in fecal neutral sterol and bile acid excretion and suppress the hyperinsulinic response in STZ-NA induced Type 2 diabetes. Another study reported that γ-Oryzanol supplemented at100mg/kg.b.w (OZ-100)and at 200 mg/kg b.w. (OZ-200) orally to STZ-NA induced diabetic rats for a period of six weeks resulted in marked improvement in serum and hepatic biomarkers of treated animals as compared to untreated ones, thereby confirming that γ-Oryzanol has hepatoprotective potential by scavenging free radicals and reducing oxidative stress thereby exerting a protective role against several metabolic diseases (Chauhan et al., 2015b; Chauhan, 2015). Similarly Al-Okbi et al., 2014 reported rice bran oil and pumpkin seed oil afford hepato protection against nonalcoholic steatohepatitis (NASH) in rats fed high fructose diet.

ANTI MUTAGENIC EFFECTS

No mutagenic activity was observed using *Salmonella typhimurium* either with or without metabolic activation. High temperatures are known to produce mutagens in deep fried food as well as in edible oils. Food deep fried in RBO showed that the oil is less absorbed in fried food when compared with food fried in GNO. In addition, neither RBO nor the fried food had any mutagenic effects in bacterial screening system (Polasa and Rukmini, 1987a; 1987b).

TOXICITY EVALUATION

The multigenerational toxicological studies were conducted to establish the safety of RBO for human consumption The study revealed that the gain in body weight and the feed efficiency ratio of GNO and RBO fed animals over 24 weeks were similar in all the three generations. In addition, it did not affect the balance of nitrogen, phosphorus and calcium in rats. The reproductive performance, as judged by the percentages of conception, birth weight, litter size, weaning weight and pre weaning mortality was also similar in animals fed either RBO or GNO (Raghuram and Rukmini, 1995).

CONCLUSIONS

Research work aimed at unraveling the potentials of RBO is still in its infancy. Same is the case with its application and utilization. However, as the available evidence indicate, this oil is hoped to have profound beneficial health

effects because of high levels of bioactive components in the prevention and management of chronic and degenerative diseases including cardiovascular diseases and cancer. γ-Oryzanol and phytosterols have the capacity to lower plasma cholesterol and decrease cholesterol absorption. Tocotrienols and γ-oryzanol act as powerful antioxidants. Because of these beneficial effects, RBO has a high nutritional value and is therefore appealing as speciality oil in niche markets. Thus, to meet the growing demands of edible oil requirements, appropriate steps should be taken to enhance its production as well as popularization.

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